Senate Environment & Public Works Committee
Expanding and Accelerating the Deployment and Use of Carbon Capture, Utilization, and Sequestration

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Written Testimony

Thank you for inviting my testimony. My name is Julio Friedmann, the CEO of Carbon Wrangler. Until recently, I served as the Senior Advisor for Energy Innovation at the Lawrence Livermore National Laboratory. From 2013 to early 2016, I served as the Principal Deputy Assistant Secretary for the Office of Fossil Energy at the US Department of Energy. I have worked for a total of 17 years on clean energy technology development and deployment focusing my work on CCUS, mostly from my positions at Lawrence Livermore National Laboratory.

Clean energy demand continues to grow worldwide, with investment of nearly $400B in 2015 and 2016. Many governments see investment in clean energy technology development and deployment as part of their strategy to remain globally competitive in transforming energy markets, and claim additional benefits from those investments (e.g., stronger heavy industrial sector, maintaining and growing jobs, and avoid the health consequences of pollution). In a global clean energy market, US is considering how best to invest in the power, transportation, and industrial energy sectors as they change nationally and globally.

In this context, carbon capture, use and storage (CCUS) remains a critically important and under-supported sector in the clean energy industry. CCUS includes carbon capture and storage (CCS), CO_2 enhanced oil recovery (EOR), CO_2 conversion and use (CO2U), and even carbon removal technology (so called negative emissions approaches, which pull CO_2 from the air and oceans). These different pathways provide real commercial and environmental opportunities for companies, communities, and governments.

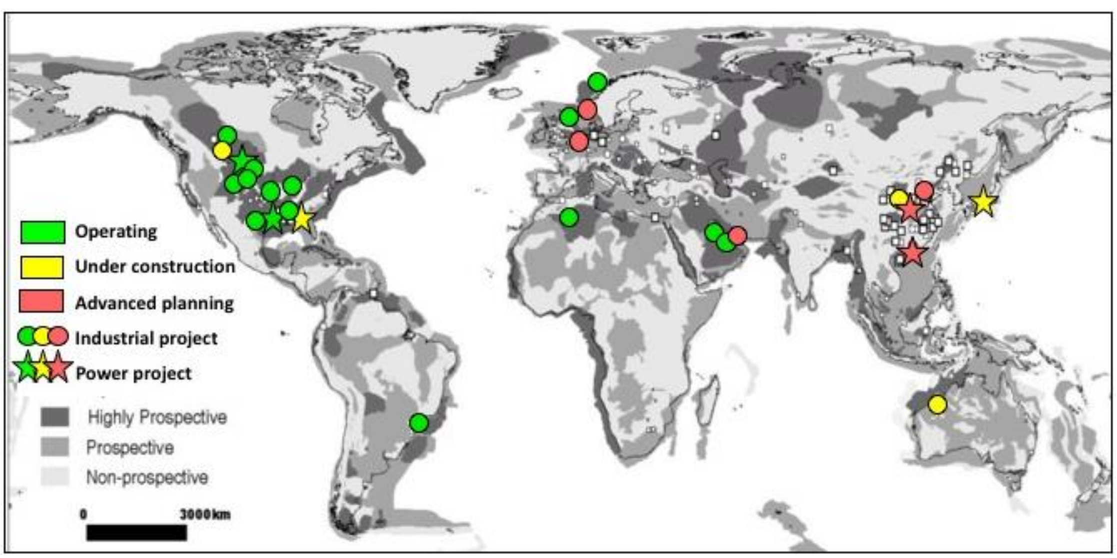

Figure 1: Operating and soon to be operating CCUS projects world-wide. Over one third of these are in North America.

Recent progress in CCUS is profound. Today, 16 commercial plants operate worldwide, and with six more planned, 22 will be operating by 2020 (Figure 1). These include power and industrial projects, new build and retrofits, and both CO_2-EOR and saline storage, with over a third in North America. Costs have come down, performance has improved, and new technologies have been born that show that CCUS can be cost competitive today with many clean energy technologies in many markets. In some sectors, like heavy industry, CCUS is the only option available at scale today.

Importantly, the challenges CCUS faces in deployment are neither fundamentally technical nor regulatory. Rather, it is that today there is no policy or set of policies in place that make it possible to finance CCUS projects. There is a gap between project costs and market prices and tariffs that prevent private capital from flowing into projects. This greatly limits deployments. While there are many potential pathways to providing policy support (see below), there is no market for CCUS absent these policies, which will severely limit the number of projects, the scale of projects, and availability of private capital to CCUS deployment. It is worth noting that of the $2.2 trillion that flowed into clean energy deployment world-wide, less than 1% went to CCUS.

Current Project Review

As noted, over 16 projects are operating in the world today, with 6 more coming online by 2020. Together, these will inject 40 million tons of CO_2 underground – like pulling 8 million cars off the road. The overwhelming majority of these projects have been completed on time and on budget, and have a successful high-capacity operating history.

In addition to these projects, there are a few additional noteworthy projects for the Committee's consideration.

PetraNova[1]: NRG, in partnership with JX Nippon and Hilcorp Energy Company, retrofit the W.A. Parish power plant near Houston, TX. Roughly 1.6 Million tons are captured by the liquid solvent technology, provided by Mitsubishi Heavy Industries, and stored during enhanced oil recovery. The project came in on time and on budget. The operators and partners say that a second project at the same site could be done for roughly 20% lower cost.

Port Arthur[2] and Quest[3]: These two industrial projects capture and store CO_2 which is a byproduct of converting methane to hydrogen. This produces very low-cost, zero-carbon hydrogen – the cheapest in the world so far. The Air Products project at Port Arthur stores the CO_2 through EOR. Shell's project at Quest stores in a saline formation.

China: Many CCUS projects are moving forward quickly in China. Dr. James Wood's testimony will explain this in some detail. However, it is worth noting that 3 large commercial projects are coming on line in the next four years, and that the Chinese Academy of Sciences has tasked a new research institute in Shanghai[4] for the sole purpose of CO_2 conversion to useful products.

NetPower Pilot Plant: NetPower[5] is a North Carolina based company that uses "Allam cycle" combustion – oxygen-fired natural gas turbines that use supercritical CO_2 as both the

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[1] http://www.globalccsinstitute.com/projects/petra-nova-carbon-capture-project
[2] http://www.globalccsinstitute.com/projects/air-products-steam-methane-reformer-eor-project
[3] http://www.globalccsinstitute.com/projects/quest
[4] http://english.sari.cas.cn/
[5] http://www.netpower.com

working fluid and mass to the turbine. The NetPower system has the same cost as a natural gas power block, has a physical footprint, and requires no water for cooling (in some configurations, the plant produces water). A pilot demonstration[6] near Houston has finished construction and begun component testing - it should be operational in fall 2017, with Exelon, Chicago Bridge and Iron, and Toshiba as commercial partners.

Climeworks Direct Air Capture Plant[7]: A small Swiss company, Climeworks, has created the first commercial, for-profit project that captures CO2 directly from the air. They capture and sell 900 tons/year of CO_2 to an organic greenhouse. This technology is mass-producible, scalable, and robust.

Carbon removal power plant: Climeworks is partnering with Reykjavik Energy in Iceland and Lawrence Livermore National Laboratory to make the world's first power plant with less-than-zero carbon emissions. Based at the Hellisheidi Geothermal Power Station[8], Climeworks is installing their direct-air capture system. CO_2 drawn from the air will then be injected into the deep basaltic rocks below the plant, part of the CarbFix project[9]. US participation will include LLNL work on the monitoring and validation of the CO_2 injection as well as the life-cycle analysis of the carbon footprint. Already, the project has paying customers.

Carbon Recycling International's Renewable Methanol Plant[10]: Also in Iceland, Carbon Recycling International has built and operated a plant that converts CO_2 to methanol, a chemical feedstock and transportation fuel. Using clean electricity from the Svartsengi geothermal power station, they make hydrogen from water and combine the renewable hydrogen with CO_2 to make methanol. This fuel is sold to ferries in Europe, which use the methanol to power fuel cells.

NOTE: The increased availability of low-cost, distributed clean power and heat helps to create new industries like Carbon Recycling International that convert CO_2 to products. Part of the likely market value of these products is the low carbon footprint. If so, then the demand for clean energy will grow as these companies gain market share – part of a new carbon economy.

Power Applications: Range of Costs and comparisons to other technologies

CCUS has many applications, including power, heavy industry (see below), and achieving negative emissions. While commonly considered a "coal" power sector technology (where it would be most valuable in reducing emissions), it can also be applied to biomass, natural gas, biogas, and even fuel cell power systems. Perhaps surprisingly, the CCUS power costs are competitive today on an unsubsidized cost basis with many other technology options (Figure 2). On an unsubsidized basis for the levelized cost of electricity (LCOE)[11], power from gas, coal, or biomass is cheaper than offshore wind, new nuclear power, rooftop solar PV, concentrating solar, and community solar PV with batteries in many US markets.

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[6] https://www.forbes.com/sites/christopherhelman/2017/02/21/revolutionary-power-plant-captures-all-its-carbon-emissions-at-no-extra-cost/#5db22e3d402d

[7] http://www.climeworks.com/

[8] http://www.onpower.is/about-us

[9] https://www.or.is/english/carbfix-project

[10] http://carbonrecycling.is/

[11] Lazard, 2016. Levelized cost of electricity analysis - version 10.0. https://www.lazard.com/perspective/levelized-cost-of-energy-analysis-100/

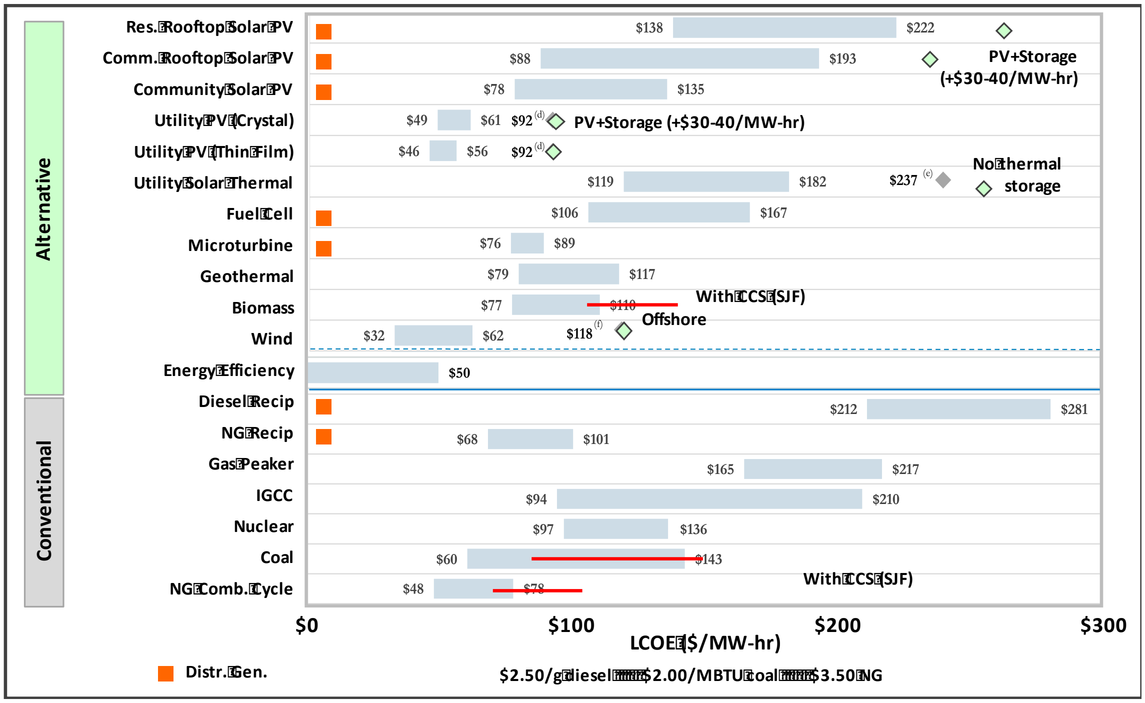

Figure 2: After Lazard (2016). Red bars reflect reported costs from commercial projects and price estimates based on DOE and NETL reports on existing technology in the market today.

Today, post-combustion retrofits on a supercritical coal plant using amine-based solvents is possible and in some cases the lowest cost pathway to decarbonization. For example, the PetraNova plant described above reduced 90% of the emissions from one unit without derating or decline in power output. Importantly, opportunities for cost reduction are major even with the same kit – CCUS coal plant operators in the US and Canada have publically stated that they could reduce costs by 20% redoing the same plant, and that the 4th plant would achieve 40-50% cost savings relative to the first.

Industrial CCUS in the US

Many heavy industries, representing 20% of global emissions, lack other options to decarbonize. Cement, steel, refining (and biorefining), chemicals, and glass making are particularly difficult cases. For cement and steel making, much of the emissions are a direct consequence of fabrication chemistry. For such systems, CCUS is the only available option.[12]

In many cases, though, by-product CO_2 is highly-concentrated (e.g., for ethanol, biodiesel, fertilizer production, natural gas sweetening, refining, and petrochemicals). These can be captured and stored at relatively modest cost. In the US, the all-in-cost of CCS, including polishing, compression, transport, and storage, is less than \$30/ton CO_2 – in some cases less than \$20. ***Over 43M tons/year could be stored at this low cost***. [13]

For this reason, perhaps unsurprisingly, most CCUS projects around the world are industrial projects. These include Emirates Steel (the first ultra-low C metallurgical plant), the Uthmaniyah refinery in Saudi Arabia, the Quest upgrader project in Alberta, the ADM ethanol plant in Decatur, Illinois, and the Air Products plant in Port Arthur, TX.

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[12] Global CCS Institute, 2016, Understanding Industrial CCS Hubs and Clusters, 2016
[13] www.betterenergy.org/American_CO2_Pipeline_Infrastructure

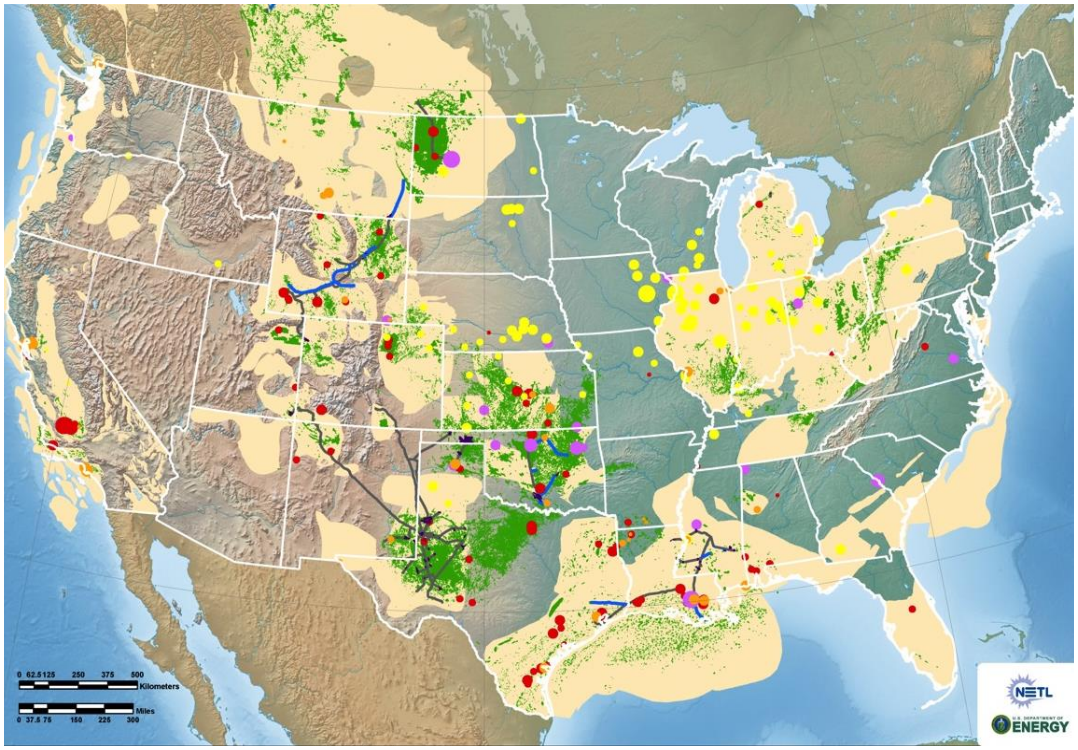

Figure 3: High-purity CO_2 sources within 100 miles of potential CO_2 storage sites. Green areas represent oil fields; light beige areas represent saline formations for storage. Yellow dots = ethanol plants, purple dots = fertilizer plants, red = petrochemicals plants, orange = oil and gas refineries.

Finance gaps and policy options

As stated above, CCUS is competitive on a pure levelized cost basis with many clean power options. However, whether CCUS is applied to power, industrial or other sectors, it is not possible to obtain financing for commercial projects. This is chiefly because it is not possible to recoup a private investment given today's policy frameworks.

Many other clean energy technologies (such as wind or solar) rightly benefit from policy support. These include renewable portfolio standards (mandating a fraction of generation), investment and production tax credits (ITCs and PTCs) which provide cash back to developers and operators, feed-in tariffs (guaranteed price supports, common in Europe), development mandates (e.g., 200,000 MW wind construction as mandated by the Chinese Govt), and others. For many years in the US and other countries, policies like this closed the gap for financing projects, and developers could recuperate their investments and pay back loans given the financial security of such policies. That created markets for clean energy, and jobs, supply chains, and wealth reaction accompanied those specific policy decisions.

CCUS projects have no access to these policies[14]. If they did, the size of these policies for other clean energy investments would large enough to close the financing gap (see Lazard[15]

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[14] Global CCS Institute, 2016, The Global Status of CCS, Summary Report

[15] Lazard, 2016. Levelized cost of electricity analysis - version 10.0. https://www.lazard.com/perspective/levelized-cost-of-energy-analysis-100/

and fig. 2 above). Lack of policies that support financing limit the flow of private capital into CCUS projects. Similarly, they limit corporate R&D investment, limit VC financing of start-ups, and limit the human capital and supply chains that come from projects. Many ministries in many countries, including the US, have called for "policy parity" to close the financing gap and help create a vibrant CCUS market.[14,16]

Ultimately, lack of financing and a CCUS market will disadvantage US companies in the global marketplace. Substantial investments in R&D and projects from the governments of Japan, China, Germany, Canada, Norway and Saudi Arabia have supported companies and projects that can take advantage of emerging CCUS markets. If the US does not create markets for CCUS companies and projects in the US, then wealth and job creation will flow to other countries.

Final thoughts

We are at the edge of a new carbon economy – one that harnesses innovation and entrepreneurship to create new products, companies, and wealth through capturing and converting fugitive carbon into value-added products. Global carbon constraints in the market will convert to product value in ways that are hard to predict, but as part of an inexorable and inevitable trend. The global economy will increasingly value low-carbon products, including goods manufactured in the US with a reduced CO_2 footprint. CCUS provides a low-cost pathway to both greater global competitiveness for US companies and for revitalizing industrial base of the US through investment and innovation. That pathway is ready for deployment today.

New policies are required to help create markets for projects, vendors, operators, and energy services in a new carbon economy - ones that can be supported through conventional financial investors that would accelerate the development and deployment of these novel technologies and industries.

[16] Carbon Sequestration Leadership Forum, November 2015. "6th Meeting of the Carbon Sequestration Leadership Forum (CSLF) Ministers: Moving Beyond the First Wave of CCS Demonstration" http://www.cslforum.org/publications/documents/CSLF_Communique.pdf